High-Mass Resonances Decaying to Leptons and Photons at the Tevatron

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The high-mass spectrum of lepton and photon pairs is sensitive to a broad range of new physics. Examples are extra dimensions and new gauge bosons such as the W' and Z'. Additionally, electron compositeness would result in excited electrons that decay into an electron and a photon. We report the latest results of searches for high-mass dilepton, diphoton, and electron-photon resonances by the CDF and D0 experiments at the Tevatron.

1. Introduction

Searches for new physics that involve high momentum electrons, muons and photons in the final state provide a clean environment to look for resonances at high mass. The standard model (SM) backgrounds are typically modeled with Monte Carlo simulation with the exception of misidentified backgrounds from QCD processes that are usually derived directly from data. Several experimental signatures will be discussed and in turn be interpreted in specific beyond the standard model theories.

2. Search for High Mass Di-Electron and Di-Photon Resonances

The large difference between the Planck scale, $M_{Pl} \approx 10^{16}$ TeV, and the weak scale presents a strong indication that the standard model is incomplete. In the Randall-Sundrum (RS) scenario [1], the space-time metric varies exponentially in a fourth spatial dimension. The wave function overlap with the SM brane is therefore suppressed, thus explaining the apparent weakness of gravity. This model predicts a tower of Kaluza-Klein excitations represented as massive graviton modes that couple with similar strength as the weak interaction. Their properties are quantified by two parameters, the mass of the first massive excitation M and the dimensionless coupling constant to standard model fields, $k/\bar{M}_{Pl}$, where $\bar{M}_{Pl} = M_{Pl}/\sqrt{(}8\pi)$ is the reduced Planck scale.

The CDF and D0 collaborations have searched for high mass resonances in the ee [2] and $ee/\gamma\gamma$ [3] final states, using 2.5 and 1.0 fb^{-1} of data, respectively. The CDF analysis requires two electrons in the central-central ($|\eta| < 1.1$) or central-forward ($2.0 > |\eta| > 1.2$) region. The CDF electrons and the D0 electromagnetic (EM) clusters must satisfy E_T>25 GeV. The left side of Figure 1 and 2 show the M_{ee} and $M_{ee/\gamma\gamma}$ spectra from CDF and D0. The D0 data are

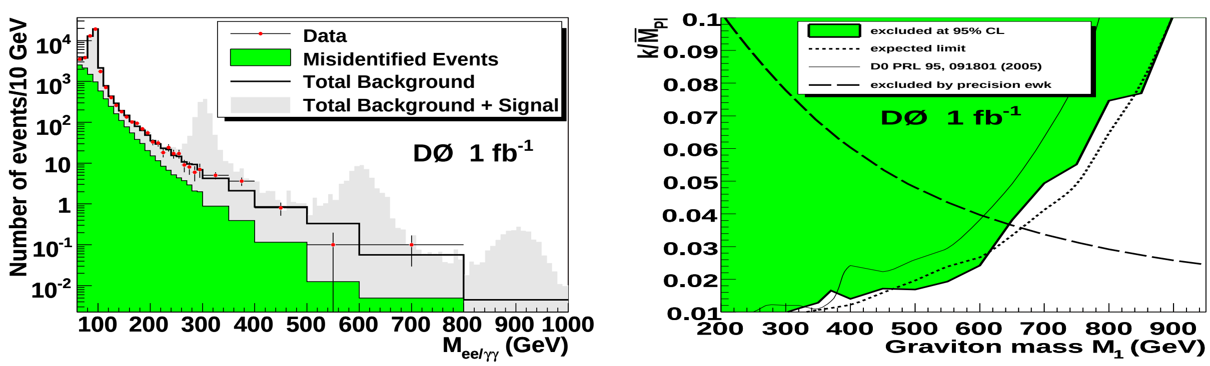

Figure 1: Left: The invariant mass $M_{ee/\gamma\gamma}$ spectrum. Right: The 95% C.L. excluded regions as a function of M and $k/\bar{M}_{Pl}$.

consistent with standard model predictions. The p-value of the largest excess in the CDF data at $228 < M_{ee} < 250$ GeV is 0.6%. Without significant excesses in both analyses, CDF and D0 set limits on the mass of RS gravitons as a function of coupling strength, as shown in Figure 1 and 2 on the right. For $k/\bar{M}_{Pl} = 0.1$, masses below 850 GeV

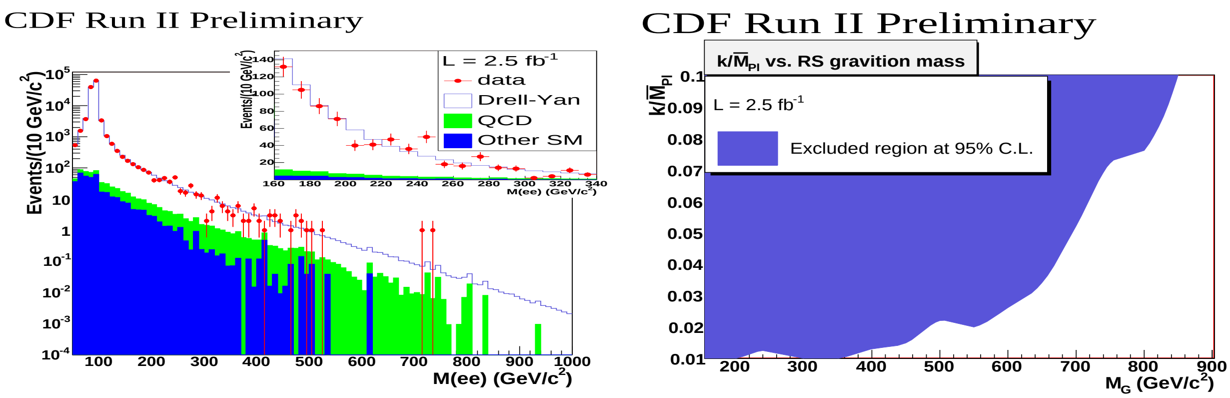

Figure 2: Left: The invariant mass M_{ee} spectrum. Right: The 95% C.L. excluded regions as a function of M and $k/\bar{M}_{Pl}$.

and 900 GeV are excluded, for CDF and D0 respectively. Using the di-electron spectrum, CDF also sets limits for Z' bosons in various models, as will be discussed in section 3.

An alternative way to circumvent the hierarchy problem is by extending the dimensionality of space, the approach in the ADD large extra dimension model [4]. This model posits that gravity propagates in n_d additional compactified spatial dimensions. Gauss's Law gives the relation between the effective Planck scale M_S, the observed Planck scale, and the size of the extra dimensions R: $M_{Pl}^2 \sim R^{n_d} M_S^{n_d+2}$. If R is large compared to the Planck length, M_S can be as low as 1 TeV. Extra spatial dimensions will manifest themselves by the presence of a series of graviton states that will result in enhancement of the cross sections above the SM values, especially at high energies. The D0 collaboration used 1.0 fb^{-1} of data with a similar selection of a combined $ee/\gamma\gamma$ final state as for the RS graviton search, but also including EM candidate showers in the forward calorimeters [5]. The data is shown on the left side of Figure 3 and is consistent with the background hypothesis. The obtained limits as a function of n_d are illustrated on the right side of Figure 3, which range from 1.29 to 2.09 TeV at the 95% C.L. for $n_d = 7$ to $n_d = 2$.

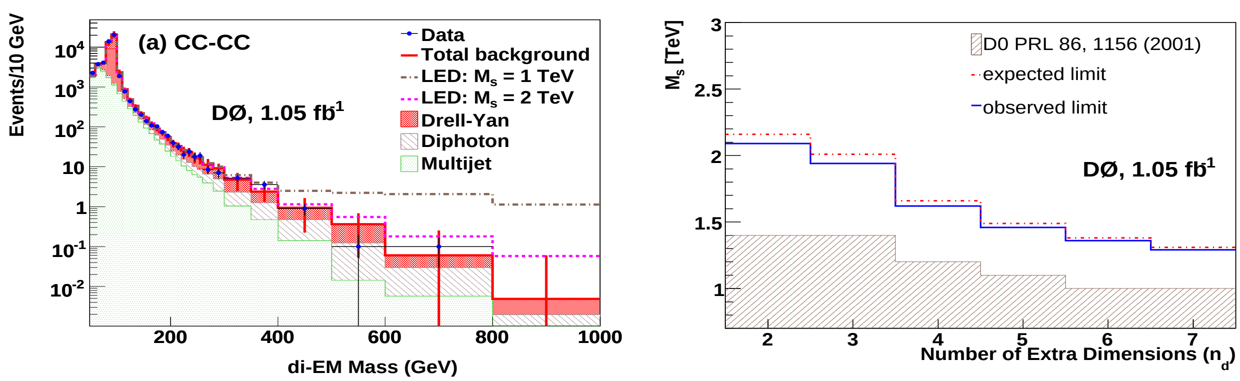

Figure 3: Left: The invariant mass $M_{ee/\gamma\gamma}$ spectrum. Right: The 95% C.L. limit on the effective Planck scale M_S vs n_d.

3. High Mass Di-Muon Spectrum

In many schemes of GUT symmetry-breaking [6], additional U(1) gauge groups survive to relatively low energies, leading to the prediction of additional neutral gauge vector bosons, generically referred to as Z' bosons. Such Z' bosons are expected to couple with electroweak strength to SM fermions, thus appearing as narrow, spin-1, resonances. Many other models, such as the left-right model, and the little Higgs models, also predict heavy neutral gauge bosons. A CDF search uses 2.3 fb^{-1} of data and selects muons with a track $p_T > 30$ GeV. The analysis uses the inverse mass spectrum as shown in Figure 4, with the benefit that the detector resolution is approximately constant over

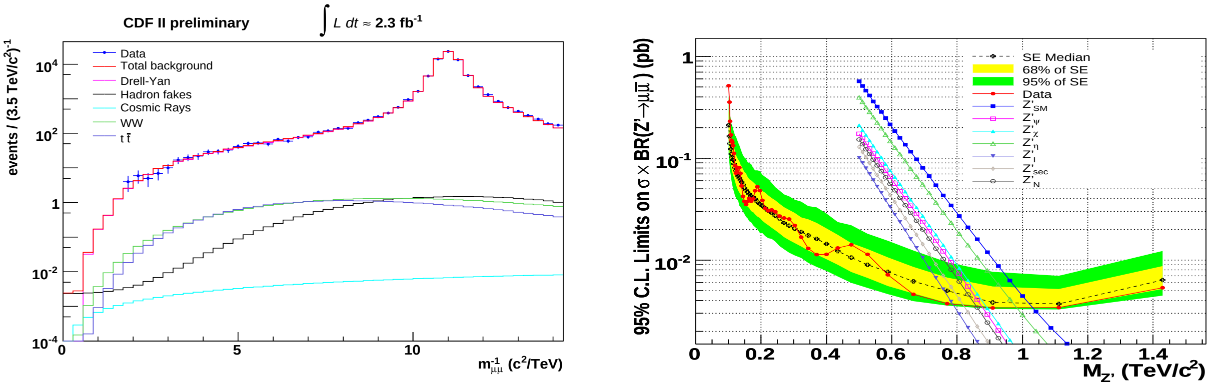

Figure 4: Left: The inverse invariant mass $m_{\mu\mu}^{-1}$ spectrum. Right: The 95% C.L. limit for various Z' couplings.

the range shown in the plot. The data is in good agreement with standard model expectations. Limits are set on Z' bosons predicted by E6 models with different couplings or assuming the same couplings to SM fermions as the Z boson, shown on the right side of Figure 4. Table I summarizes all the derived lower mass limts for the CDF di-muon search as well as the CDF di-electron search described in section 1. CDF also extracts limits for spin-2 RS gravitons

Table I: Z' Mass Limits

Channel	Z'_I	Z'_{sec}	Z'_N	Z'_ψ	Z'_χ	Z'_η	Z'_{SM}
CDF $\mu\mu$	789	821	861	878	892	982	1030
CDF ee	737	800	840	853	864	933	966

Table II: Graviton Mass Limits

Channel	$k/M_{Pl} = 0.01$	$k/M_{Pl} = 0.1$
CDF $\mu\mu$	293	921
CDF ee	358	850
D0 $ee/\gamma\gamma$	300	900

using the di-muon final state. Table II summarizes the derived mass limits from the CDF $\mu\mu$ final states and the from the CDF ee and D0 $ee/\gamma\gamma$ final states discussed in section 1.

4. High Transverse Mass Electron-Neutrino Spectrum

Additional charged gauge bosons, W' bosons, have been introduced by several new physics models, such as left-right symmetric and E6 models. The D0 collaboration has searched for a W' decaying to an electron and a neutrino using 1.0 fb^{-1} of data [7]. Events are required to have a central electron with E_T>30 GeV and $\not{E}_T$>30 GeV. There is no excess in the high transverse mass spectrum, shown on the left of Figure 5. Using the Altarelli reference model

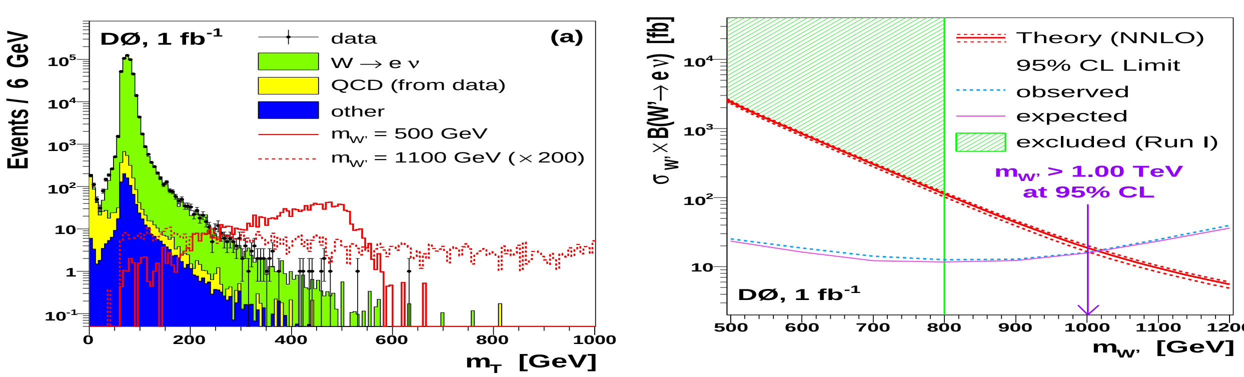

Figure 5: Left: The transverse mass m_T spectrum. Right: The 95% C.L. limit as a function of W' mass.

[8], where SM couplings are assumed, W' with masses below 1 TeV are excluded at 95% CL, shown on the right side of Figure 5.

5. High Mass Electron-Photon Spectrum

The observed fermion multiplicity motivates a description in terms of underlying substructure, in which all quarks and leptons consist of fewer elementary particles bound by a new strong interaction. In this compositeness model, quark-antiquark annihilations may result in the production of excited lepton states, such as the excited electron [9]. The D0 collaboration searched for associated di-electron production followed by the radiative decay e$\rightarrow e\gamma$ in 1.0 fb^{-1} of data [10]. The analysis considered single production of an excited electron e* in association with an electron via four-fermion contact interactions, with the subsequent electroweak decay of the e* into an electron and a photon. Figure 6 on the left shows the $e\gamma$ invariant mass which shows good agreement with the SM prediction. Figure 6 on

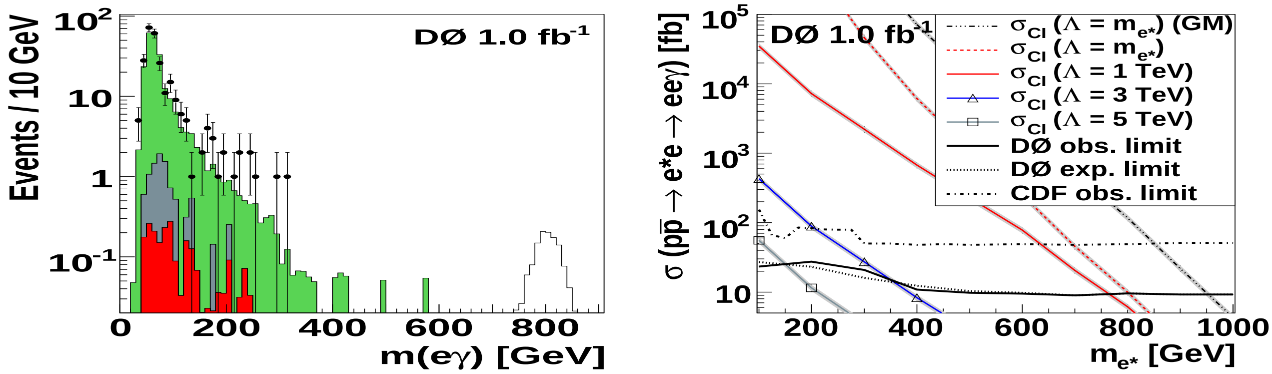

Figure 6: Left: The invariant mass $m_{e\gamma}$ spectrum. Right: The 95% C.L. limit as a function of contact interaction scale Λ.

the right shows the 95% C.L. limits for various values of the interaction scale Λ. For $\Lambda = 1$ TeV, masses below 756 GeV are excluded.

6. Conclusions

The CDF and D0 collaborations have an extensive program to look for resonances in the high mass lepton and photon final states. Analyzing 1.0-2.5 fb^{-1} of data, no significant excess above the standard model expectations is observed. The derived mass limits on new physics for e.g. new gauge bosons, W' and Z', RS Gravitons, excited electrons and large extra dimensions are currently the world's most stringent.

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References

[1] L. Randall and R. Sundrum, Phys. Rev. Lett. 83, 4690 (1999); Phys. Rev. Lett. 83, 3370 (1999).
[2] T. Aaltonen *et al.*, arXiv:0810.2059 (2008).
[3] V.M. Abazov *et al.*, Phys. Rev. Lett. 100, 091802 (2008).
[4] N. Arkani-Hamed, S. Dimopoulos and G. Dvali, Phys. Lett. B **429**, 263 (1998).
[5] V.M. Abazov *et al.*, arXiv:0809.2813v1 (2008).
[6] J.L. Rosner, Phys. Rev. D 35, 2244 (1987).
[7] V.M. Abazov *et al.*, Phys. Rev. Lett. 100, 031804 (2008).
[8] G. Altarelli *et al.*, Z. Phys. C **45**, 109 (1989).
[9] U. Baur, M. Spira and P.M. Zerwas, Phys. Rev. D **42**, 815 (1990).
[10] V.M. Abazov *et al.*, Phys. Rev. D **77**, 091102(R) (2008).